The UK Electric Gun Programme in 1998

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Abstract - The UK is undertaking research into both electromagnetic (EM) and electrothermal-chemical (ETC) propulsion for future weapon systems. In the EM field, efforts have been concentrated in the railgun armature area. Recent work has tried to reduce the parasitic mass of base-push solid armatures, since this leads directly to lower launch energies and greater overall system efficiency. The aim is to understand the many property requirements needed to allow velocities over 2000 ms^{-1} with full mass payloads. The use of multi-material armatures has been shown to be beneficial both theoretically and through examination of hardware recovered after firings at Kirkcudbright. Conditions at high velocities and energies have been found to be vastly different from those at more moderate levels, and support the UK decision to tackle the problems in these difficult regimes.

Recent ETC research effort has spanned the topic from the fundamental to the systems' levels. The fundamental plasma-propellant interactions continue to be studied. Enhanced gas generation rates (EGGR), both during and in some cases after the electrical discharge, have been studied in a wider variety of propellant types and geometries. The scaling of plasma generators has been investigated. A plasma jet type of plasma generator has been operated successfully in open-air at a peak electrical power of 3 GW. The concept of muzzle velocity control of artillery guns known as "Smart Gun" has also been studied. Analysis indicates that the concept has the potential to significantly improve artillery precision.

I. Introduction

The last major published review of the UK electric gun programme was presented at the 8th EML Symposium in 1996 [1]. Since that date, a significant amount of work has been carried out, resulting in a much greater knowledge of the fundamentals of this new technology. The focus for the work remains the same as before, i.e. electromagnetic (EM) launch for high velocity direct fire applications (tanks) and electrothermal-chemical (ETC) propulsion to increase the performance of large calibre artillery systems. Both programmes are well established and enjoy good MOD customer support.

If EM guns are to achieve more than just paper promise, they will need to demonstrate improvements in direct fire attack of armour targets. The EM launcher work has an agreed set of criteria that the technology should meet by the end of the century. These criteria cover a number of aspects relating to the use of this method of propulsion for high velocity direct fire attack of armour targets.

The ETC work is being conducted jointly with Royal Ordnance (RO). DERA is responsible for most of the theoretical, chemical and electrical underpinning work, whilst RO perform medium calibre (30/45 mm) gun firings. This work is moving rapidly towards large calibre 155 mm trials of ETC artillery concepts.

II. Electromagnetic Launchers

In 1996, very little armature design work had been undertaken in the UK. A baseline 90 mm armature had been used for virtually all the firings up to then. This had been successfully fired at Kirkcudbright at typical ordnance velocities (1500-1700 ms^{-1}) with conventional aluminium alloy saboted long rod penetrators, and at higher velocities at the Green Farm test site in the US. However, the armature weighed approximately 1.2 kg, and represented a significant proportion of the whole launch mass of 3.5 kg. As the velocity had to be raised beyond 2000 ms^{-1}, there was obviously some development effort needed in this area. The goals of increasing the velocity, imposing greater thermal, mechanical and electrical loads on the armature, whilst trying to reduce its mass, were challenging to the UK team.

Before this work started, however, an accuracy trial was fired from the 90 mm IAP laminated gun. A dozen rounds were fired at the 1000 m range target. Limitations imposed by the gun meant that the shots had to be fired at around 1550 ms^{-1}. Additionally, the movement of the bore gave problems in using the conventional gun boresight, used to lay the gun onto the target. An interface tube was designed to reduce the effects of the non-circularity of the gun near the muzzle, and a consistent aiming method developed to further reduce errors. As a result, the apparent consistency of the gun improved with time, even though the bore condition was deteriorating. No inter-shot honing was possible then.

The results demonstrated that EM guns could achieve satisfactory accuracy and consistency. Earlier fears that such guns could suffer from an anomalous electrical effect which caused them to shoot wildly were clearly disproved. Despite the fact that the experimental gun was far from ideal, the results were clear enough to ease the minds of any doubters.

Once this trial was completed, the gun became available for armature experiments. It was deemed unsuitable for firing more advanced projectiles because of the bore irregularities and dilation under firing loads. Projectile firings at higher energies and velocities were postponed, pending further strengthening of the IAP gun, or availability of a stronger stiffer barrel.

Efforts to reduce the parasitic mass of solid armatures included both design and materials options. Earlier trials at 40 mm [1] showed that no one alloy had the range of mechanical and electrical properties required in a monobloc armature. The balance of properties depends strongly upon the exact duty cycle of the armature, and varies with payload, calibre and velocity, to name but a few. At this point in the programme, a total launch mass of 3 kg was chosen for future 90 mm armature designs. Power supply limitations were dominant in deciding this value.

Two ultra-lightweight armature designs were shot. These had approximately one and two thirds the leg length of the baseline design. Both transitioned early in the launch cycle, due to their reduced capability to handle the applied electrical action, and significant amounts of plasma were ejected from the breech of the gun. Additionally, the shorter version was observed to be highly unstable in-bore, due to its poor l/d ratio, Fig.1. It was obvious that there was to be no dramatic mass reduction, and that design changes would have to be evolved.

Over the course of a year or so, nineteen 90 mm armatures were fired, and over 75% were physically recovered by careful searching of the ground in front of the gun. These recovered pieces were closely examined and, in conjunction with the normal electrical and X-ray data recorded, allowed selective changes to be made to various parts within the armature body. Some mass was removed from the base of the armature, until observations after firing showed that this region was suffering physical distortion at muzzle exit. The velocity in these tests was around 2000 ms^{-1}, still a long way short of that ultimately desired for a weapon system. The distortion was felt to be due to magnetic separation forces caused by the current at muzzle exit trying to open the armature legs. There was some evidence for this, but it was not conclusive. No further material was removed from this region.

Attention was next paid to the armature legs. The baseline design had fairly thick parallel legs, which survived intact beyond 2000 ms^{-1}. The legs were tapered down and then subsequently thinned (Fig.2), without affecting in-bore performance. However, the recovered armatures showed that most of the current was carried at the edges of the legs, and that the central leg or part of a leg merely served to prevent leg collapse under the magnetic forces. Electrical conductivity is definitely of paramount importance in the current carrying parts of solid armatures.

Armatures made of different aluminium alloys in a variety of heat treatment conditions were fired at velocities around 2000 ms^{-1}. The results showed that a trade-off of room temperature mechanical strength for increased conductivity was worthwhile, even at 90 mm calibre. However, it was also clear that no single material had the breadth of properties for the highest energies and velocities.

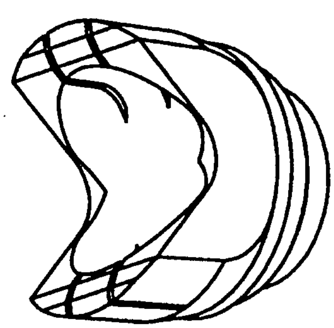

Fig.1. Ultra-lightweight 90 mm armature

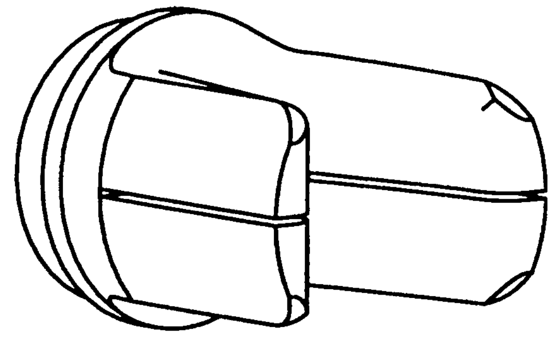

Fig. 2. Tapered leg 90 mm armature

Friction welding different aluminium alloys together had been tried at the smaller 40 mm calibre, with reasonable success, and this technique was employed for the production of full scale 90 mm armatures. A number of different designs of increasing complexity and optimisation were made and fired. The latest design employs a combination of A7075 with commercially pure aluminium at the corners of the legs where they contact the rail edges. The A7075 is positioned with the grain directions to suit the particular part of the armature. The details of this are reported elsewhere at this Symposium.

Trials have also continued at 40 mm calibre, looking at other problems associated with high velocity projectile launching. On many occasions, the centring bands have failed in-bore, and efforts are underway to rectify this problem. Changes to both the design and material used are being employed. Improvements have been noted, but the problem has not been totally solved yet.

The smaller calibre gun has also been used for initial trials of split armatures, as will be featured on any mid-riding armature/sabot design of projectile. A simple option as shown in Fig.3 has been successfully launched at 2000 ms^{-1} and further work is planned with firings of more representative designs.

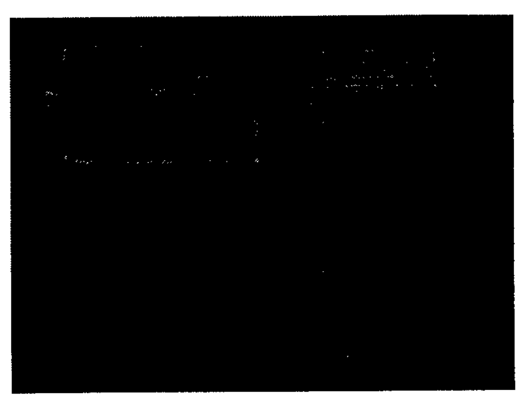

Fig.3. Split 40 mm armature before firing

III. ELECTROTHERMAL-CHEMICAL RESEARCH

Early ETC gun research concentrated upon establishing experimental facilities and techniques, developing plasma generator concepts and investigating plasma-propellant interactions. Work towards a fundamental understanding of these ETC processes continues whilst increasing emphasis has been placed upon the transition to large scale testing and the evaluation of applications. The UK ETC programme is focused towards indirect fire guns, principally artillery and naval fire support. ETC technology is considered capable of improvements in many aspects of an indirect fire gun system including; range, zoning, accuracy, consistency, logistics and survivability.

Research on fundamental aspects of ETC technology has recently included the further development of a mathematical model of capillary plasma generators, the measurement of plasma properties, and the study of plasma-propellant interactions.

EDENET is a one dimensional (1D) multi-species hydrodynamics code used to simulate the operation of capillary plasma generators. It is being developed for DERA by Fluid Gravity Engineering Ltd. Its main features are:

- an electrical circuit model;
- joule heating effects;
- wire vaporisation model;
- magnetic diffusion (1D radial);
- thermal and radiative diffusion (1D radial);
- electrode erosion;
- SESAME tabular equation of state / resistivity models.

Recently, radial simulations have been used for early times in the operation of the capillary plasma generator and have helped clarify the wire vaporisation process and subsequent plasma development. The information gained has been used to develop the axial version of the code into a multi-zone model to better simulate the radial temperature profile and thus the radiative energy transfer. Fig.4 shows some preliminary results where the predictions of a development version of the revised EDENET code are compared with experimental data.

Investigations into the use of plasma to increase the gas generation rates of solid propellants [2,3], have continued. Efforts to identify the mechanisms causing enhanced gas generation rates (EGGR) both during the electrical discharge (EGGRDED) and post electrical discharge (PEDEGGR) involve a theoretical study of the chemical reaction kinetics, a theoretical study of the heating of solid propellant grains and an experimental parametric investigation aimed at developing empirical relationships for use in internal ballistics codes. In two series of closed vessel tests using plasma jet and current injection modes the magnitude of EGGR was measured to be approximately proportional to the input electrical power. The development of empirical relationships has recently yielded tentative evidence for supporting a hypothesis that EGGR is a function of gas temperature and hence heat transfer to the propellant grain.

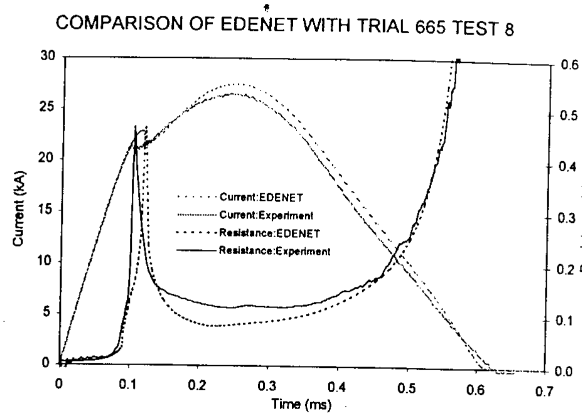

Fig. 4. Predicted and measured capillary plasma generator parameters

A number of both intra-chamber and extra-chamber plasma generator designs have been studied. The design closest to full scale realisation is the capillary plasma generator (plasma jet). Open air firings of an 18 mm diameter plasma jet recently achieved a peak electrical power of 3 GW, a peak current of 460 kA and dissipated an electrical energy of 3 MJ.

ETC scaling issues are being investigated with the aid of specially designed apparatus such as a "medium scale" test vessel (MSTV) and a 155 mm gun simulator. The MSTV is currently undergoing commissioning and will be capable of a peak pressure in vented vessel mode of 600 MPa, use propellant masses of up to 1 kg and up to fifteen instrumentation ports. The 155 mm gun simulator is depicted in Fig.5. The purpose of this device was to investigate plasma jet firings into low zone artillery charge modules with chamber dimensions and pressure history similar to those of a 155 mm artillery ordnance.

In particular it was to be a precursor to full scale gun firings, reducing the associated technical risks. A series of firings were undertaken at DERA Kirkcudbright with plasma ignition and conventional ignition followed by plasma injection at close to peak pressure. The results showed an elimination of ignition lag compared with

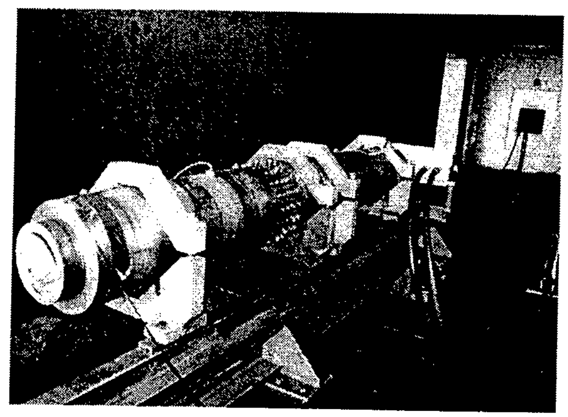

Fig. 5. ETC 155 mm ballistic simulator

conventional ignition and demonstrated EGGR during propellant burning. As the firings were consistent with predictions, preparations for full scale gun firings are continuing. The technique for increased gun precision through muzzle velocity control known as "Smart Gun" has been an active area of study [4]. This relies on an accurate prediction of projectile muzzle velocity within the first few metres of projectile travel along the bore so that an electrothermal impulse can be imparted to the projectile to increase the velocity of slow rounds. Where projectile muzzle velocity variations are a large fraction of the range error budget this concept has the potential to significantly improve artillery precision. Recent work includes an evaluation of fibre-optic strain gauges as projectile position sensors, the development of muzzle velocity prediction algorithms and tests to measure the velocity of propagation of electrothermal energy along a gun barrel. More details of this work will be presented elsewhere at this symposium.

Near-term future work will concentrate on the planned firing of a 155 mm ETC gun at the Kirkcudbright Electromagnetic Launch Facility. This is scheduled for July 1998. Figs.6 and 7 illustrate the gun assembly to be used. Early firings will use a plasma jet to ignite low zone charge modules and fire L17 projectiles. The aim of these tests will be to demonstrate improved internal ballistics of low zone unimodular charges by using ETC technology. Future work will aim to develop a true unimodular ETC charge system, investigate ETC advanced charges and demonstrate the smart gun concept.

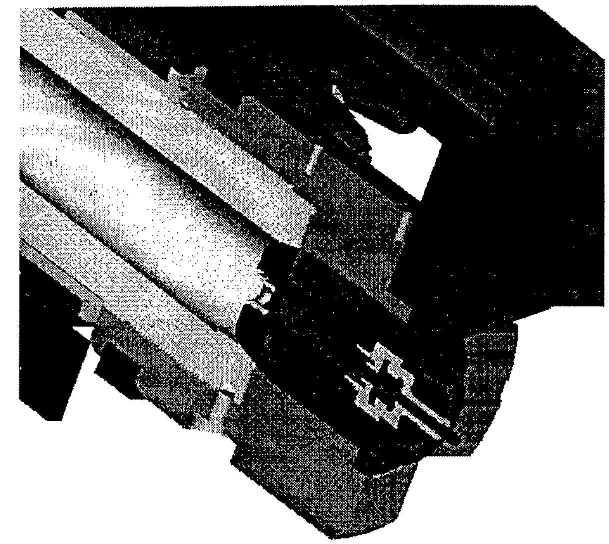

Fig.7. 155 mm ETC experimental gun: Breech and plasma generator

IV. Conclusions

Research into electric guns in the UK is well established, and the demonstration of large scale performance is close. The EM work has shown that a hypervelocity weapon system is not a dream, but a realisable target. Understanding of the properties required of solid armatures has grown significantly and techniques to achieve the required combination of properties are being developed. This work will combine with work on novel projectiles to produce ballistic performance well in excess of that possible from conventional powder guns. The imminent availability of the Task C laminated barrel on loan from the US should help to provide even better launch conditions for these projectiles. ETC work has moved on from the early paper studies and small scale tests. Work towards a fundamental understanding of ETC processes continues, but more emphasis is being placed upon large scale testing. The programme is entering a phase of intense experimental activity using a large calibre 155 mm test gun. This will aim to validate theoretical predictions which are currently supported by small scale tests. It will also serve to highlight the issues involved in the realisation of an ETC weapon system.

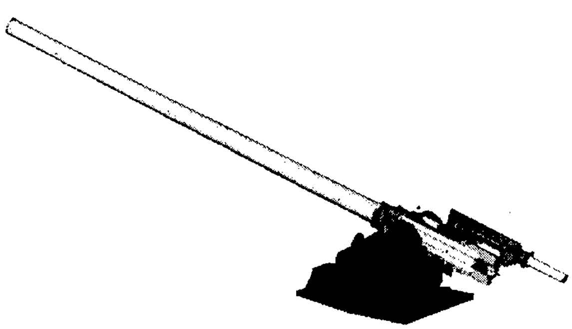

Fig.6. 155 mm ETC experimental gun assembly

Acknowledgements

The authors gratefully acknowledge inputs from many members of the electric gun teams, notably Grant Hainsworth, Kevin Wales, and Gordon Thomson of the EM team, and Grant Savell, Steve Fuller and Clive Woodley of the ET team. This work was funded by the UK MOD.

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